SUMMARY AND CONCLUSIONS

Climatic data presented in this study were collected during the 20-year period, 1914 to 1934, within the four main vegetational zones, designated as piñon-juniper, oakbrush, aspen-fir, and spruce-fir, ranging in elevation from 5,575 feet to 10,100 feet, on the west front of the Wasatch Plateau in central Utah. Observations were made with standard meteorological equipment by the Great Basin branch of the Intermountain Forest and Range Experiment Station, near Ephraim, Utah. The United States Weather Bureau cooperated in furnishing a number of the instruments used in the study.

Data summarized in this report include: Precipitation and atmospheric temperatures in the four vegetational zones; soil temperatures and amounts of soil moisture in the oakbrush, aspen-fir, and spruce-fir zones; extent of cloudiness in the piñon-juniper and aspen-fir zones; and relative humidity determinations in the aspen-fir zone.

As shown by these data, precipitation and atmospheric temperatures of the area vary widely between vegetational zones, owing to differences of elevation and topography. Total annual precipitation varies from 11.70 inches in the piñon-juniper zone on the valley floor, to 29.48 inches in the aspen-fir zone near the middle of the plateau front, and 28.01 inches in the spruce-fir zone at the summit. Of these totals, 45 percent, 70 percent, and 80 percent, respectively, is received during the winter season, November 1 to May 1, in the form of snow. The remainder falls in the form of moderate rains distributed throughout the summer season, May 1 to November 1. Summer thunderstorms are interspersed with rainless periods which occur during the main growing season and have extended for 158 days, and longer, between occurrences of 0.50 inch or more precipitation.

The month of June, a critical period for plant growth, receives the least precipitation in all zones. A secondary rainy season occurs during July and part of August, followed by an extreme dry period that extends into October.

The trend of precipitation for the 34-year period, 1901 to 1934, inclusive, at the piñon-juniper zone shows considerable periodic variation characterized by above- and below-normal precipitation. Consecutive years with below-normal precipitation have numbered as many as 12 during this time.

Temperatures as high as 101° F. have been recorded in the piñon-juniper zone and as low as −30° in the oakbrush and aspen-fir zones.

The growing season within the area is extremely short, the frost-free period being only 90 days in the oakbrush, 87 days in the aspen-fir, and 80 days in the spruce-fir zones.

In view of the limited amount and sporadic nature of precipitation and the extremes in atmospheric temperatures during the short growing season, plans for proper management of this area must recognize the delicate balance between this existing climate and the vegetational cover and provide for moderate grazing use and controlled timber-cutting practices.

Such a program will maintain an adequate plant cover which will guard against serious soil erosion and insure a permanent water supply sufficient to meet the needs of the adjacent communities. Also, records of the existing climate indicate that areas already depleted of plant cover can be rehabilitated only by controlled grazing use and by planting forage species especially adapted to withstand the drought periods and extreme fluctuations in temperature characteristic of this area.

LITERATURE CITED

(1) Alter, J. C. 1919. Normal Precipitation in Utah. MONTHLY WEATHER REV. 47: 633–636, illus.
(2) Bates, C. G. 1924. Forest Types in the Central Rocky Mountains as Affected by Climate and Soil. U. S. Dept. Agr. Bull. 1233, 152 pp., illus.
(3) ——— and Henry, A. J. 1928. Forest and Stream-Flow Experiment at Wagon Wheel Gap, Colo. MONTHLY WEATHER REV. Sup. 30, 79 pp., illus.
(4) Henry, A. J. 1919. Increase of Precipitation With Altitude. MONTHLY WEATHER REV. 47: 33–41, illus.
(5) Milham, W. I. 1934. Meteorology. 549 pp., illus. New York.
(6) Pearson, G. A. 1931. Forest Types in the Southwest as Determined by Climate and Soil. U. S. Dept. Agr., Tech. Bull. 247, 144 pp., illus.
(7) Sampson, A. W. 1918. Climate and Plant Growth in Certain Vegetative Associations. U. S. Dept. Agr. Bull. 700, 72 pp., illus.
(8) Weaver, J. E., and Clements, F. E. 1929. Plant ecology. 520 pp., illus. New York.

THE GEOMETRICAL THEORY OF HALOS—V

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IMAGES PRODUCED BY SIMPLE REFLECTION

Superimposing figure 7 on the celestial sphere, we have figure 17 and formulae D for the calculation of an image produced by simple reflection from an arbitrarily oriented plane with normal inclined at any angle ψ' to the vertical.

When the reflecting plane is vertical, $\psi'=90°$ and

$$\begin{aligned} D&=180°-2i,\\ \cos A'&=\tan\frac{D}{2}\tan H, \qquad (D^*)\\ H'&=H,\\ \sin\frac{\zeta}{2}&=\sin\frac{D}{2}\sec H, \end{aligned}$$

as may be found either directly from formulae D or by constructing the corresponding special case of figure 17. The rotation of a vertical plane about a vertical axis will therefore distribute the reflected light in a right cone with vertical axis and with one of its generators parallel to the incident ray; the locus of the images formed by this conical dispersion is a small circle parallel to the horizon.

When the reflecting plane is horizontal $\psi'=0°$, $i=90°-H$; and either from formulae D or directly from figure 7,

$$\begin{aligned} D&=2H,\\ A'&=180°, \qquad (D^{**})\\ H'&=-H,\\ \zeta&=0°. \end{aligned}$$

The rotation of a horizontal plane about a vertical axis will not disperse the reflected light at all, but will merely form a vertical image as far below the horizon as the source is above.

IMAGES PRODUCED BY PRISMATIC REFRACTION COMBINED WITH INTERNAL REFLECTION

In the most general case of *reflection from an arbitrary plane* (figure 11), with the *refracting edge in any position*, we may use formulae *C* (figure 16) except of course that the angles D', D, and A will be obtained from formulae III

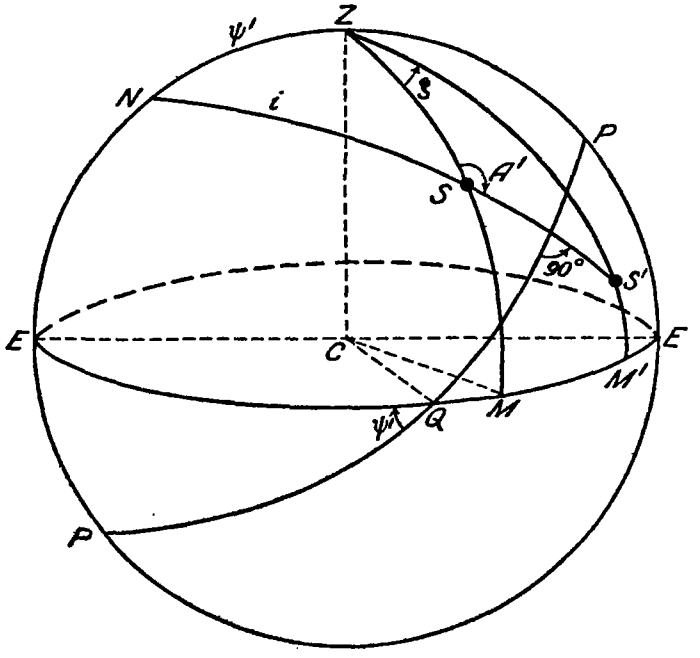

FIGURE 17. *Calculation of the image produced by simple reflection.* See formulae *D*. *Z*, zenith; *EME*, horizon; *S*, luminary, at altitude *H*; *PQP*, reflecting plane; *N*, pole of reflecting plane; *S'*, image; $SS'=D$, deviation; *A'*, position angle; ζ, azimuth; $S'M'=H'$, altitude of image. *S'* away from *N*.

FORMULAE D

CALCULATION OF THE IMAGE PRODUCED BY SIMPLE REFLECTION

Parameters: H; ψ', $0°\leq\psi'\leq180°$ $\psi'<90°$ when normal is directed upward; $\psi'>90°$ when directed downward.
Argument: i, $|\ 90°-(H+\psi')\ |\leq i\leq 90°$.
Calculation of D, A'; H', ζ:

(1) $D=180°-2i$ away from N

(2) $$\cos A'=\frac{\sin\frac{D}{2}\sin H-\cos\psi'}{\cos\frac{D}{2}\cos H}$$

(3) $$\sin H'=\cos D\sin H+\sin D\cos H\cos A'$$

(4) $$\sin\zeta=\frac{\sin D\sin A'}{\cos H'}$$

[See fig. 17. In the triangle NZS, the Law of Cosines gives $\cos\psi'=\cos i\sin H+\sin i\cos H\cos ZSN$; whence, solving for $\cos ZSN$, and using $A'=180°-ZSN$ and (1), we obtain (2). Formulae (3) and (4) follow from the Law of Cosines and the Law of Sines, respectively, in triangle ZSS'. For given H and ψ', minimum value of i occurs when N happens to lie on the solar vertical.]

instead of from I. When $\psi=0°$ (*refracting edge vertical*), all that is necessary is to put $h=H$, $-h'=H'$, $D'=\zeta$, $A=A'$ in III (in the same way that formulae *A* were derived from I). Likewise, when $\psi=90°$ (*refracting edge horizontal*), we may similarly modify formulae *B* in accordance with III by using III—8 in place of *B*—3 to obtain r'_1, putting h' (given by III—6) for h in B—6 and B—7, replacing B—9 by III—10 and B—11 by III—11 to obtain D and A, and appropriately modifying B—8 and B—12 to

(8*) $$\zeta=\begin{cases}\theta+\omega & D'+\delta<90°\\ (180°-\theta)+\omega), & D'+\delta>90°\end{cases}$$

(12*) $$A'=\left\{\begin{array}{ll}ZSP'-\mathrm{A}\text{----------} & D'+\delta>90°\\ A-ZSP' \quad D' \text{ upward} & \\ 360°-(A+ZSP'),\ D' \text{ downward} & \end{array}\right\} D'+\delta<90°$$ (B*)

as shown by figure 18; the resulting collection of formulae,

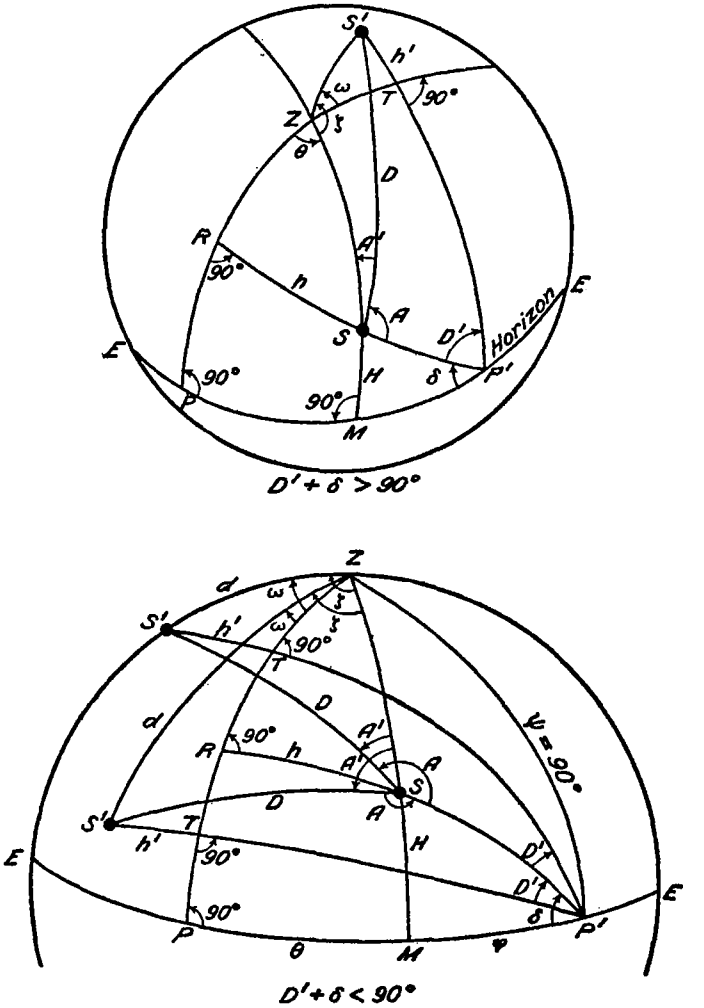

FIGURE 18. *Calculation of image produced by refraction combined with internal reflection when refracting edge is horizontal* (formulae *E*). *Z*, zenith; *EME*, horizon; *S*, luminary; *S'* image, *ZRP*, principal plane; *D*, deviation; *A'*, position angle; *d*, zenith distance; ζ, azimuth.

which may readily be written out explicitly when needed, will be referred to as **Formulae E.**

When the *reflection occurs from a principal plane*, formulae I* replace III in the foregoing discussion: With the *refracting edge in any position*, use formulae *C* except that D' is found from I—5 and the angles D and A from I*. With *refracting edge vertical*, put $h=H$, $D'=\zeta$, $A=A'$, $H'=-h$ in I*. With *refracting edge horizontal*, replace *B*—9 by I*—6* and *B*—11 by I*—7* to obtain D and A, and modify *B*—8 and *B*—12 in the same way as above; the resulting formulae will be referred to as **Formulae F.**

The systematic application of formulae A to F, inclusive, to the crystal angles and faces of given forms of ice crystals, in all orientations and at various altitudes of the luminary, will give the loci of the images that can be produced by refraction and reflection. The results obtained will be presented in succeeding papers.